

Agent-based Large-Scale Emergency Evacuation Using Real-Time Open Government Data

Wei Lu, Ph.D.

Phone: 865-576-9297

Email: luw4@ornl.gov

Cheng Liu, Ph.D.

Phone: 865-576-5593

Email: liuc@ornl.gov

Budhendra L. Bhaduri, Ph.D.

Phone: 865-241-9272

Email: bhaduribl@ornl.gov

Geographic Information Science and Technology group
Computational Science and Engineering Division
Oak Ridge National Laboratory
PO BOX 2008 MS6017
Oak Ridge, TN 37831-6017

Abstract

The open government initiatives have provided tremendous data resources for the transportation system and emergency services in urban areas. This paper proposes a traffic simulation framework using high temporal resolution demographic data and real time open government data for evacuation planning and operation. A comparison study using real-world data in Seattle, Washington is conducted to evaluate the framework accuracy and evacuation efficiency. The successful simulations of selected area prove the concept to take advantage open government data, open source data, and high resolution demographic data in emergency management domain. There are two aspects of parameters considered in this study: user equilibrium (UE) conditions of traffic assignment model (simple Non-UE vs. iterative UE) and data temporal resolution (Daytime vs. Nighttime). Evacuation arrival rate, average travel time, and computation time are adopted as Measure of Effectiveness (MOE) for evacuation performance analysis. The temporal resolution of demographic data has significant impacts on urban transportation dynamics during evacuation scenarios. Better evacuation performance estimation can be approached by integrating both Non-UE and UE scenarios. The new framework shows flexibility in implementing different evacuation strategies and accuracy in evacuation performance. The use of this framework can be explored to day-to-day traffic assignment to support daily traffic operations.

Keywords: open government data, urban transportation systems, high resolution data, evacuation management,

1. Introduction

Global urbanization has boosted the population growth unprecedentedly, which has also increased the travel demand and transportation infrastructure demand in urban areas. Natural or man-made disasters (e.g. Atlanta ice snow in 2014, Boston Marathon bombings in 2013) have tremendous impacts on urban transportation systems. How to maintain essential transportation operations during critical infrastructure disruption is an important issue.

The increasing availability of open government data has provided many new opportunities. Robinson et al. explained the benefits of using government data in public services (Robinson, Yu, Zeller, & Felten, 2008). Ding et al. introduced an open source portal to support the deployment of linked open government data in today's international open government initiatives (Ding et al., 2011). Janssen discussed current policies and practices of using public sector data in Europe. He also proposed the legislation concerns about the conflict between data access and re-use (Janssen, 2011). Since the data.gov became available online in 2009, many applications were developed to provide useful information for publics (Hendler, Holm, Musialek, & Thomas, 2012). However, most of these researches and applications are not used in emergency evacuation areas, especially for real-time operations. To meet the Obama open government initiatives, Seattle government provides real time fire 911 calls data publicly, which updates every five minutes (data.seattle.gov, 2014), which can be used in real-time emergency evacuation planning effectively. This provides the opportunity to discover urban population dynamics during emergency situations.

Agent-based traffic simulation models have been well explored in traffic and transportation planning and operation domain. Agent-based behavior models are developed to describe the individual driving behaviors from system level to intersection level (Dia, 2002; Doniec, Mandiau, Piechowiak, & Espié, 2008; Nagel & Flötteröd, 2009). Besides these agent-based modeling studies for transportation simulation in relative small areas, large-scale agent-based microscopic traffic

simulation based on queuing theory is explored for multiple applications and empirical case studies in Europe (Balmer, Axhausen, & Nagel, 2006; Balmer, Cetin, Nagel, & Raney, 2004; Cetin, Burri, & Nagel, 2003; Meister et al., 2010). Evacuation planning and operation also needs simulation-based studies while real world evacuation data is hardly available. Microscopic simulation package VISSIM and macroscopic simulation package DynaSMART-P are compared for emergency evacuation scenarios and emphasized the advantage of using intelligent transportation systems to route evacuees (Han, Yuan, Chin, & Hwang, 2006; Yuan & Han, 2009). Chen and Zhan (2006) used an agent-based technique to model traffic flows at individual vehicle level and revealed that the road network structure and population density have impacts on evacuation strategies. Jha, Moore, and Pashaie (2004) used microscopic simulation model (MITSIM) to model the evacuation of Los Alamos National Laboratory. Cova and Johnson (2002) presented a method to develop neighborhood evacuation planning with microscopic traffic simulation in the urban - wildland interface. TRANSIMS (Transportation Analysis and Simulation System) was also used in evacuation simulations. Lu and Han discussed the impacts of zoning resolutions on evacuation performance with various travelers' compliance rates (Lu, Han, Liu, Tuttle, & Bhaduri, 2014). Naghawi and Wolshon (2011) discussed multi-modal evacuation network performance through microscopic traffic simulation. Agent-based simulations can provide detailed information of individual vehicles, which helps evacuation operation managers to produce detailed evacuation strategies.

In order to take advantage of the real time open government data, especially under abnormal conditions, we propose a computational framework, World Wide Emergency Evacuation (WWEE), which enables emergency managers to use open data and detailed simulations in a scalable, real-time manner for efficient traffic operations. A comparison study using Seattle fire 911 data for evacuation simulation is conducted to evaluate the framework accuracy and evacuation efficiency. Two aspects are considered, including user equilibrium condition of

dynamic traffic assignment models (User Equilibrium vs. Non User Equilibrium), and temporal population resolutions in evacuation start times (daytime vs. Nighttime). The simulation results indicate that the effectiveness of our WVEE framework and various impacts of data and model resolutions on evacuation performance. Subsequent discussions on improving evacuation simulation accuracy and efficiency through high resolution demographic data are also presented.

2. Framework Description

LandScan population data and open-source agent-based traffic simulation package TRANSIMS provide valuable data and programs to build an efficient and accurate evacuation assignment and simulation platform. LPC-based traffic assignment brings many new issues to integrate modules in TRANSIMS package. A new evacuation framework built on several programs in TRANSIMS is proposed, as shown in Figure 1.

There are nine modules in this agent-based evacuation modeling framework, which convert the raw input data at the beginning to detailed simulation performance results at the end. It can provide both aggregated traffic information and individual vehicle tracking analysis.

1. Selection. According to the Seattle Fire 911 records, select the longitude and latitude values from Seattle open data website as the centroid of fire evacuation zone. The original input data are LandScan USA population (daytime/nighttime) and OpenStreetMap (Haklay & Weber, 2008) road network data. The users define an evacuation area by circle or polygon based on the selected centroid point. All the affected population and origins/shelters locations are summarized in two new files, as selected population and evacuation area. LandScan Global population data and OpenStreetMap (OSM) can be implemented for simulating areas outside US.

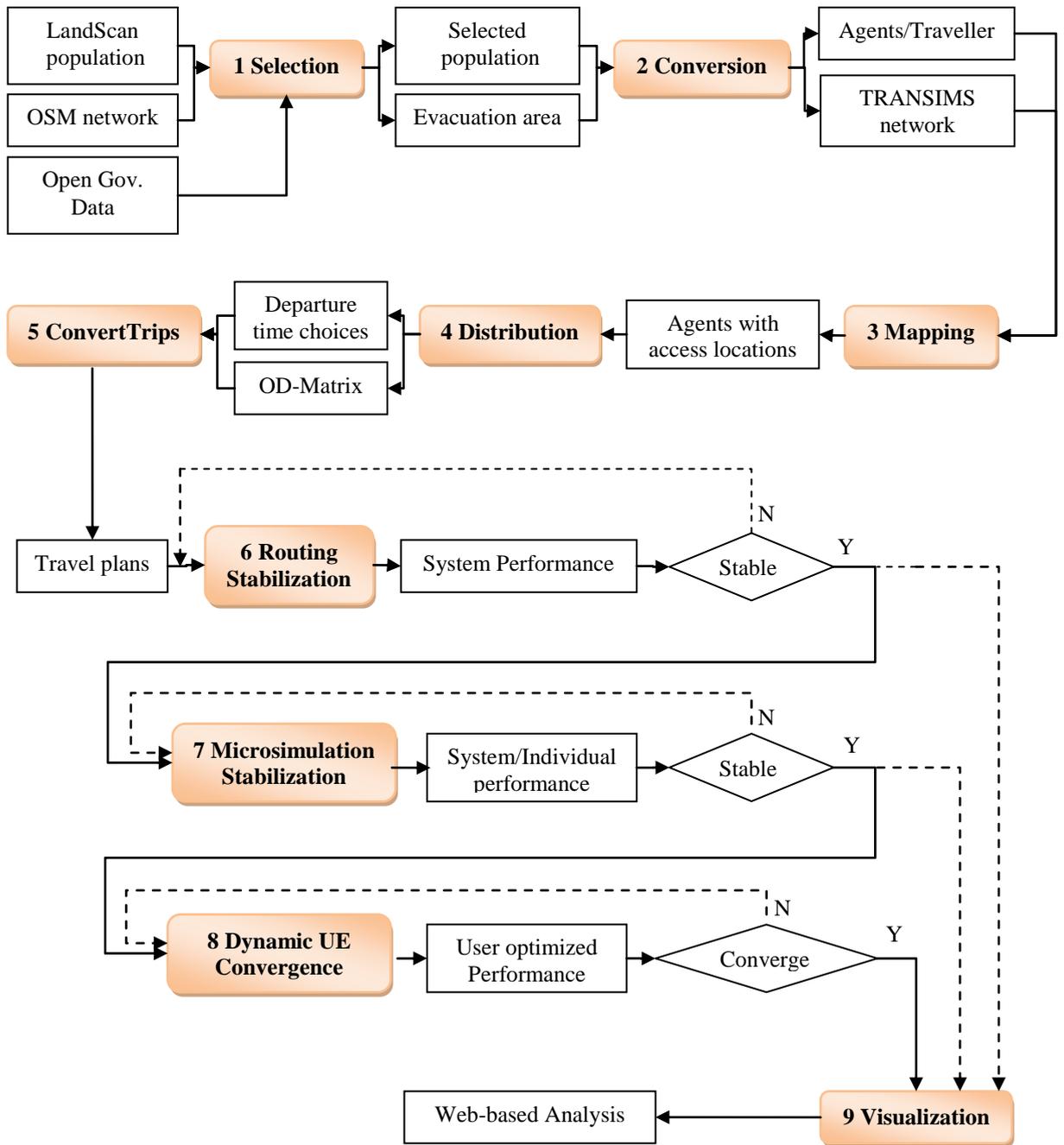


Fig. 1. Flow Chart of World-Wide Emergency Evacuation framework

2. Conversion. To take advantage of TRANSIMS simulation tools, the selected OSM road network is converted to TRANSIMS-based format. The population is converted to vehicle agents based on demographic information.

3. Mapping. The mapping module assigns the travelers in each LandScan cell to their nearest activity locations. Vehicles access to the network through activity locations along the road. This module is used to resolve the limitation of activity-based traffic simulation in TRANSIMS. The original program assumes that there are at least two activity locations in a Traffic Analysis Zone (TAZ) for inner-zone trips and at least one activity location for inter-zone trips. This is understandable in TAZ since the TAZ is usually large enough to include several road segments. But LandScan Population Cell (LPC) size is much smaller than TAZ and there are many cells having no roads crossing through their areas. In this case, the trips in that zone cannot be assigned to the activity locations. Also, the original TRANSIMS algorithm evenly assigns all the trips in one TAZ to all the activity locations in that zone. In the real world, travelers prefer to access roads at the nearest spots to their locations.

4. Distribution. Each LandScan USA population cell (LPC) is assigned as one origin zone. All the exit nodes generated in the first module are assigned as destinations/shelters. The OD matrix can be generated as formula (1) with minimum travel cost to each LPC. The travel cost can be calculated as equation (2), where impedance can be summarized with different shortest-path based routing algorithms, including shortest network distance routing, highway-based routing, and straight-line distance routing. In this evacuation model, only the shelters out of the evacuation area are considered.

$$\text{Min} \{ \text{Travel Cost}_i, i \text{ is the } i^{\text{th}} \text{ LPC} \} \quad (1)$$

$$\text{Travel Cost}_i = \sum_j \text{Impedance}_j, j \text{ is the } j^{\text{th}} \text{ link in a route} \quad (2)$$

5. ConvertTrips. This is a program provided by TRANSIMS to generate travel plans for every individual traveler with OD-matrix and used-defined departure

time choice model (or loading curve). Trip chain can also be implemented. But in this paper, we assume that all the vehicles travel to shelters directly after evacuation order is placed. TRANSIMS only consider 1000 TAZ zones as maximum for trip assignment. There are more than 1000 LPC cells in Alexandria. Technically, each LPC is equivalent to one TAZ zone. This limitation has been adjusted to accommodate LPC-based traffic assignment method.

6. Routing Stabilization. To save the computational time, link-based trip assignment is implemented to generate macroscopic system performance results. There is a loop to optimize the results to achieve stable status. Volume/Capacity ratio, travel time change ratio, et al. can be used as the condition statement. After the macroscopic simulation is stable, the results can be pulled to the last visualization module for analysis.

7. Microsimulation Stabilization. Microscopic simulation is also implemented if the users want to see detailed simulation results of each vehicle for operation management. Similar to the module 6, users can use those ratios to decide the number of iterations to achieve stable condition. The simulation results are also able to be plotted for intermediate analysis.

8. Dynamic UE Convergence. To improve the simulation accuracy, dynamic traffic assignment is also integrated to simulate user optimized evacuation dynamically. The convergence conditions are defined by users, such as less than 2% changes in travel time for each vehicle. The final outputs with both system level information and individual vehicle movement are summarized.

9. Visualization. Beyond the research analysis with output data, the simulation results file is processed to display on a web-based application front-end with both macroscopic and microscopic information.

This framework provides a one-stop application tool for both researchers and practitioners. To test our concept of using open government data, we implement a case study in Seattle. However, our framework can also handle simulations outside US with LandScan Global data and OSM networks.

3. Evacuation Case Study Design

To assess evacuation efficiency with this proposed WVEE framework in different scenarios, an evacuation case study using data in Seattle, Washington is conducted through comparing with conventional TAZ-based traffic assignment.

3.1. Data resources

The Seattle real time fire 911 calls data provides real-time emergency situations monitoring within the city. It is updated every five minutes. The attributes include address, type, date/time, location (latitude, longitude), and incident number. Users can choose the location by different types, which contains aid response, medic response, auto fire alarm, auto medical alarm, bark fire, etc. In practice, users can analyze a group of records and define a centroid point of affected area. In our case study, we just choose one location with fire alarm for demonstration purpose. We use the latitude/longitude values of a record near downtown Seattle area as the centroid to draw an elliptical shape (as shown in Figure 2), which is equal to a circle area after projection to Cartesian coordinates system used in traffic simulation.

As stated in the WVEE framework, population distribution and road networks are two major input data for the evacuation assignment. The road network of selected Seattle area is shown as black lines in Figure 2. The background map source is from OpenStreetMap in Esri ArcGIS 10.1 software package.

LandScan USA population cell (LPC) data has a high resolution population distribution to provide 90m x 90m (3'x3') resolution with national population distribution data (Bhaduri, Bright, Coleman, & Urban, 2007). It is much more accurate than conventional TAZ because some TAZ zones are large in scale or dense in population (Lu, 2013; You, Nedović- Budić, & Kim, 1998). Compared to TAZ-based traffic assignment that generates trips from large-scale zones, LPC-based methods allow small-scale, cell-to-cell trip generation.

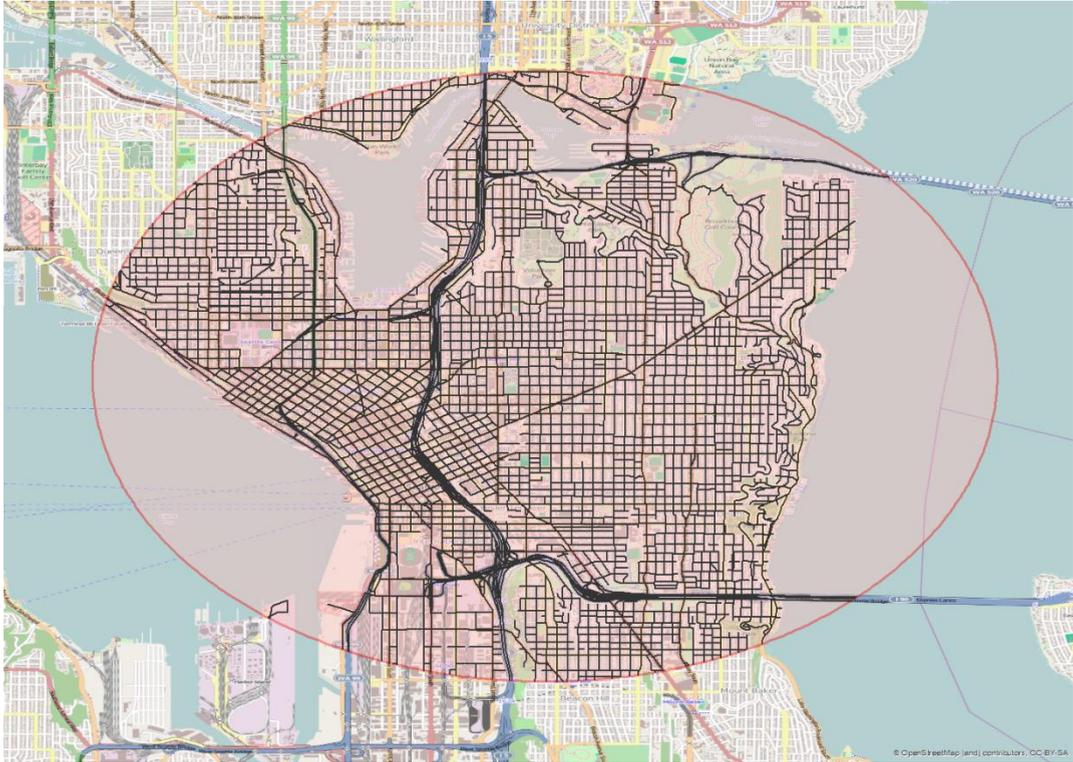


Fig. 2. Selected evacuation area and road network

In addition, LPC provides both day-time and night-time population distributions. The daytime is defined from 6:00am to 6:00pm and the nighttime is the left 12 hours. The LPC daytime data consists of 6614 non-zero cells, as shown in Figure 3a. The color represents cells with the number of population gradually, from red as high dense population to yellow as low population. Technically, TAZ and LPC have the same zone definition, but LPC size is much smaller. The total daytime population in Alexandria is 395,670 with a cell of maximum population as 6059. The LPC nighttime data is consisted of 4851 non-zero cells as displayed in Figure 3b. The total nighttime population is 159,363 with a cell of maximum population as 948. During the daytime, the total population are almost doubled compared to nighttime situation.

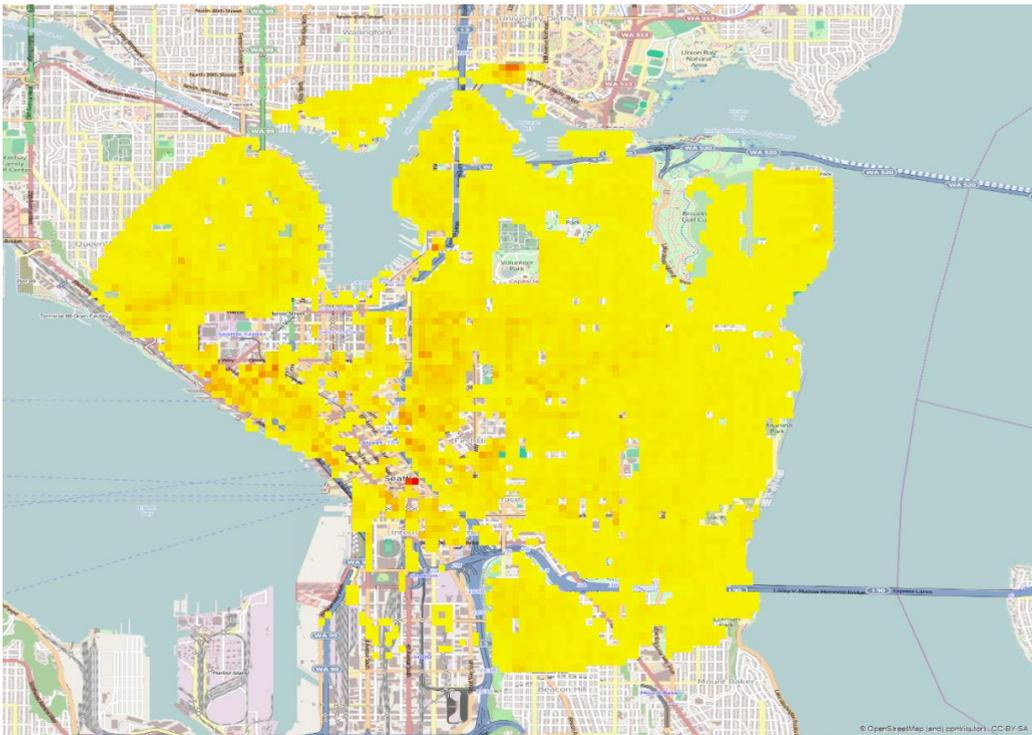
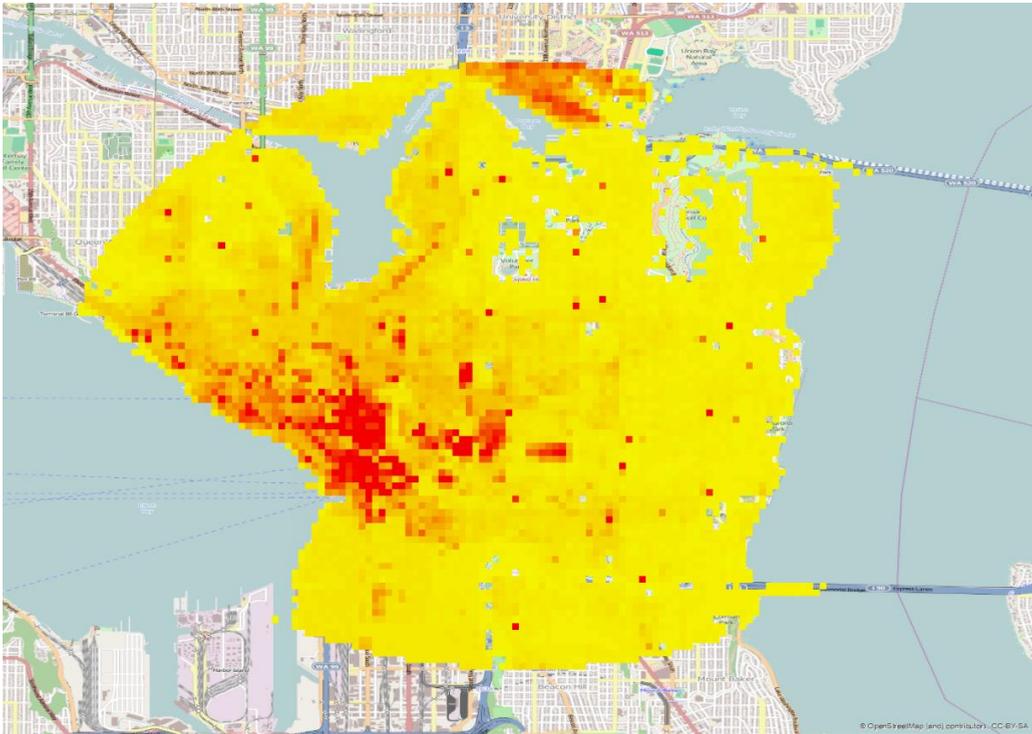


Fig. 3a. LandScan USA 2011 daytime population data in selected Seattle area
3b. LandScan USA 2011 nighttime population data in selected Seattle area

3.2. Traffic Simulation Modeling

Based on the selected Seattle road network map in Figure 2, a detailed network configuration is generated for the agent-based microscopic simulation. This includes 2136 nodes, 2336 links, 1614 activity locations, and 392 traffic controls. The Alexandria area is about 42.2 sq. mi. In our case study, only personal vehicle mode is considered. The traffic mode, such as transit, can be implemented later. The trip chain for each traveler is “walk-drive-walk”, which means walking to the car from origin, driving to the nearest parking lot at destination, and then walking to assigned shelters. After considering the vehicle per capita ratio and car pool possibility during evacuation in Seattle, the total trips for evacuation in selected area are 168,520 in daytime and 106,150 in nighttime as travel demand. In addition, 45 shelters are assigned and connected one-to-one with 45 exits of the road network. Evacuation trips generally move outward as evacuees leave an evacuation area and seek safety.

For the departure time choice models, S-shape loading curves are most accepted with empirical studies (Murray-Tuite & Wolshon, 2013). We adapted the Weibull distribution as our default model in WWEE. The Weibull distribution model is given by

$$D(t) = 1 - \exp(-\beta t^\gamma) \quad (1)$$

where $D(t)$ is the cumulative percentage of people who left at time t . The values of β and γ determine the shape of the distribution for faster or lower response to evacuation. We defined most people tried to access the road within the first five hours after evacuation orders placed.

Trip distribution models explain where people are willing to go as their safe destinations. In WWEE, we assume travelers will choose their nearest shelters outside the evacuation area. The evacuees in each LPC cell as S choose the nearest destination out of D based on travel time. The objective function is to find the minimal initial travel time for people in each LPC cell. If using Dijkstra's shortest

path algorithm with forward star structure, we have to run S times shortest path algorithm to find the O-D pair for each source node and destination node, where S is the number of LPC source nodes. The time complexity is $O((E + V) * \log V)$. If we connect all the destinations to a dummy super node and reverse the network with backward star structure, as shown in Figure 3, we can have the same O-D matrix output but with just one time run of Dijkstra's algorithm. The time complexity for our proposed algorithm is $O(((E + D) + (V + 1)) * \log(V + 1))$. It saves the computational time significantly. After testing on five different sizes networks, our algorithm reduced the computational time exponentially (500 to 45,000 times faster than conventional Dijkstra's shortest path algorithm).

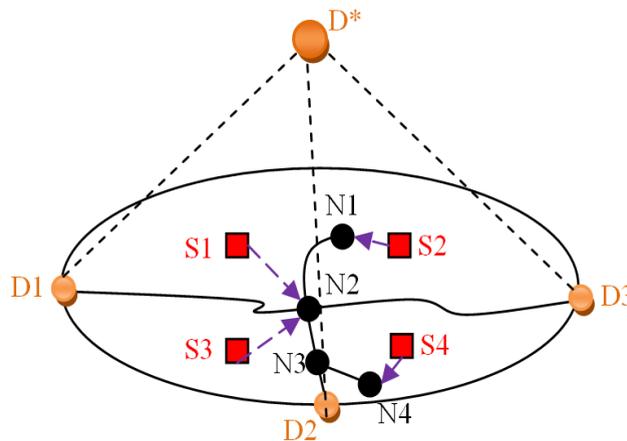


Fig. 4. Demonstration of super node trip generation

Traffic assignment models determine how travelers get access to the road network and which routes they choose to approach destinations. As stated earlier, we use activity based traffic assignment model to connect each LPC to its nearest activity location. User equilibrium is commonly used for normal traffic simulation to achieve better representation of real-world traffic scenarios through multiple iterations. However, there is a controversial debate about the effectiveness of user equilibrium in evacuation simulations (Pel, Bliemer, & Hoogendoorn, 2012). The traffic pattern and travelers' behavior are quite different during emergency evacuation scenarios. Travelers might only use the most used roads as their

evacuation routes, which is also one reason for highway congestion during empirical observations of historical evacuation events. Here, we implemented dynamic traffic assignment with and without user equilibrium (UE) conditions and let users to choose their best models. Meanwhile, multiple-threads based parallel traffic simulation model based on cellular automata theories is also completed to provide comparison between macroscopic and microscopic simulations.

3.3. Simulation Scenarios

There are two aspects of parameters considered in this study: traffic assignment models resolution (simple Non-UE vs. iterative UE) and data temporal resolution (Daytime vs. Nighttime). In total, 4 evacuation scenarios are modeled in this paper: NUE-Daytime, UE-Daytime, NUE-Nighttime, and UE-Nighttime. The proposed framework was run on a Window 7 64-bit laptop computer. The configuration of this laptop is 16GB RAM, 2.6GHz Intel(R) Core(TM) i5-3320 CPU with 4 cores, and 500GB hard disk. A 12-hour simulation time is used and the other parameters are set as stated in the preceding sections. To adjust the impact of random number in the framework, all the simulation results are based on the average of 30 independent runs. To evaluate the evacuation efficiency of microscopic simulations, we used the evacuation clearance time, evacuee arrival rate, average individual travel time, and model computational time in this study (Han, Yuan, & Urbanik II, 2007).

4. Simulation Results and Discussions

Evacuation simulation results from comparison studies of the selected Seattle area are summarized in Table 1. The non user equilibrium (NUE) assignment in daytime scenario needs the longest evacuation clearance time. First, the daytimes trips is about 1.5 times as the nighttime trips, which increases the system total travel time and congestion possibility. Second, the NUE assignment doesn't consider the situation that travelers might use alternative routes to approach their destinations. In this situation, some road sections (such as highway and major city

roads) are highly used when travelers don't have the information about other roads conditions. Thus, for the same temporal resolution, daytime or nighttime, NUE scenarios need more time to clear evacuation than UE. For the same traffic assignment condition in Seattle case study, evacuation during the daytime needs more time to achieve clearance than nighttime. The average travel time follows the similar patterns as evacuation clearance time. The longer clearance time is mainly caused by congestion on the road network during evacuation. The congestion increases travelers' average travel time. The computation time is the time period for the computer to finish one scenario simulation. In either daytime or nighttime scenarios, UE needs more computation time than NUE. To achieve user equilibrium condition, iterative simulation is run until reaching the UE status. There are 7 iterations for the daytime scenario and 2 iterations for the nighttime scenario. Basically, the iteration helps reduce the congestion conditions by re-routing some travelers to alternative routes.

Table 1. Evacuation simulation summary for different scenarios

Temporal Resolution	Traffic Assignment Conditions	Evacuation Clearance Time (hours)	Average Travel Time (minutes)	Computation Time (minutes)
Daytime	NUE	14.8	38.3	16.3
	UE	11.9	26.9	72.2
Nighttime	NUE	7.9	19.3	8.1
	UE	6.5	17.4	15.8

The impacts of temporal high resolution data with daytime and nighttime formats under user equilibrium condition are summarized in Figure 5. Similar in table 1, the daytime scenario needs more time to achieve 100% arrival rate. Under the same travel demand model, fewer trips in nighttime scenario improve evacuation efficiency than daytime scenario. However, during real-world emergency evacuation, we cannot expect fewer trips during the daytime.

Emergency managers and transportation planners can make efficient policy to control the travel demand, such as staged evacuation strategy. It gives the priority to people in seriously emergent area to access the road network for evacuation. The LandScan high resolution population data can also help estimate the critical areas to maximize the evacuated population.

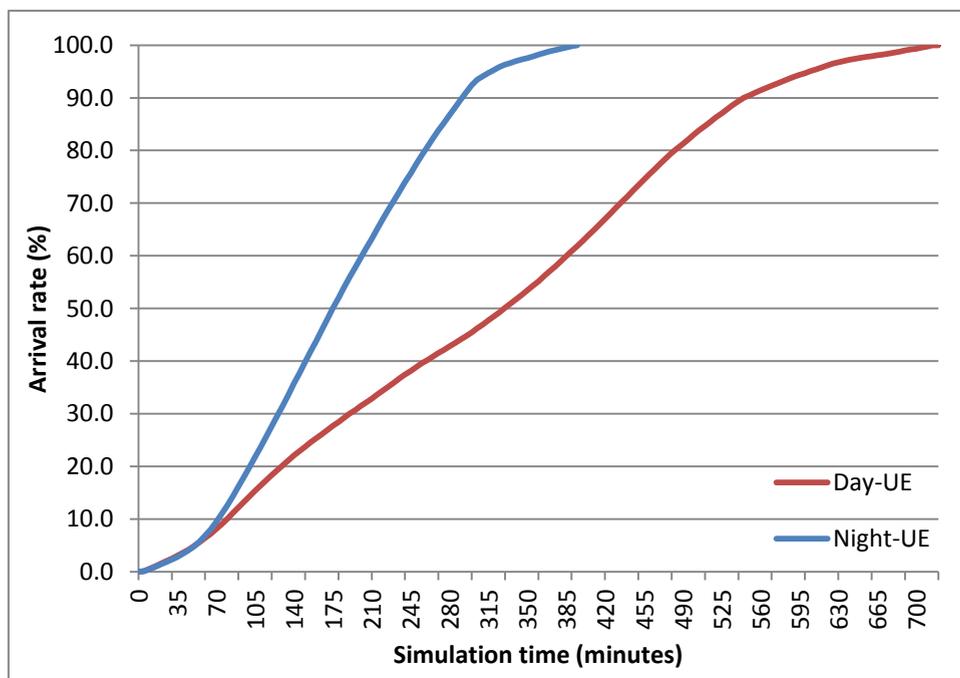


Fig. 5. Evacuation arrival rates for daytime and nighttime comparison study

Figure 6 illustrates the impact of user equilibrium conditions of traffic assignment on evacuation performance in both daytime and nighttime scenarios. For the 12 hours simulation in daytime scenarios, the UE assignment achieves 100% arrival rates, but the NUE assignment only reaches 89.1% arrival rates. The cases in nighttime scenarios have similar pattern with less simulation time to achieve 100% arrival rates. In these four scenarios, UE assignment improves evacuation efficiency by re-routing trips to alternative routes. However, travelers might not have the real-time system road condition information during emergency evacuation. They would still use the pre-defined routes after they access the road network if there is no further information provided. Real time traffic information

through intelligent transportation systems can expand travelers' knowledge about road conditions and overall performance. This helps travelers to re-route during evacuation to find the shortest path to arrive destinations. For a practical estimation of evacuation performance for planning purpose, the parameters values about evacuation efficiency locate between UE situation and NUE situation.

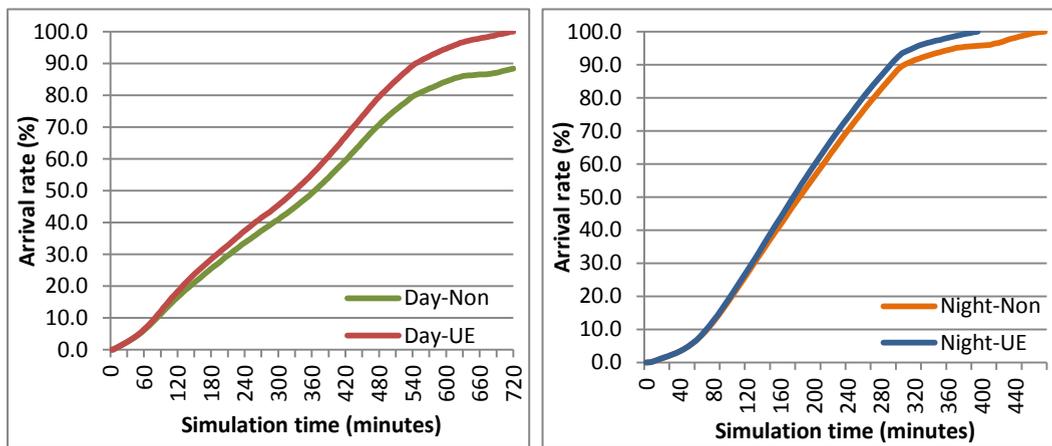


Fig. 6. Evacuation arrival rates for assignment condition comparison study

In order to improve user experience for various clients, we developed a visualization tool vehicle-based microscopic analysis. The web-based microscopic visualization tool provides detailed animation of vehicle movement, which helps identifying the network choke points during evacuation. The visualization tool can also help users to re-run their models or to test different evacuation strategies. Figure 7 shows a snapshot of microscopic visualization. Each point means a vehicle. Users can select different simulation areas from the website <http://gisthal.ornl.gov/wwee>. The animation time step ranges from 1 second to 15 minutes. The 15-minutes interval animation produces equivalent outputs of the macroscopic visualization. Clients can select certain time to indicate using LandScan daytime or nighttime population data for evacuation simulations. Clients can also drag the control button to display results at any time slot during an evacuation simulation.

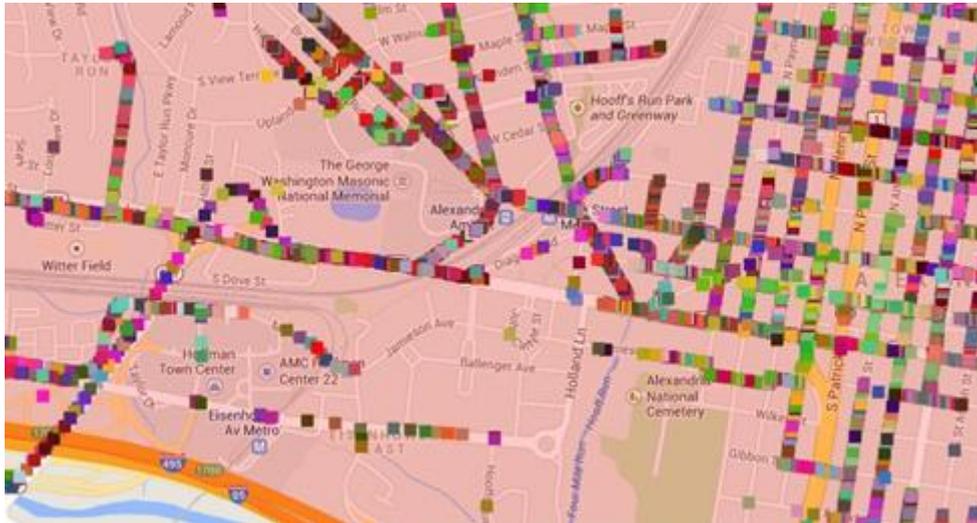


Fig. 7. Agent-based microscopic visualization tool

5. Conclusions

In this paper, a World-Wide Emergency Evacuation (WVEE) framework using high resolution data, open source data, and open government data is presented for evacuation planning and simulation. To test the effectiveness and efficiency of this framework, comparison studies using population data in different temporal resolutions and traffic assignment conditions are conducted. Through simulation studies of those four scenarios in selected Seattle area, three major findings are concluded here.

- Open government data and open source data provide great opportunity to explore urban transportation systems under emergency evacuation scenarios. There is still space to improve the open government data quality for wider usage. For example, the traffic count data from Seattle Department of Transportation is out-dated. It only provides 2007, 2008, 2009 years data. This kind of data can be used to validate and calibrate traffic simulation models.
- Urban population dynamic information varies according to temporal resolutions. In this Seattle case study, the daytime scenario requires more evacuation preparation time compared to nighttime scenarios. Most existing

studies using Census data are actually only consider the nighttime scenarios. The temporal data resolution can improve model accuracy.

- Traffic assignment with user equilibrium condition is commonly used for traffic simulation modeling. But it does not consider the real emergency situation well. A better estimation can be reached by integrating both UE and non-UE scenarios.

This high spatiotemporal resolution traffic assignment framework can be easily expanded to simulate any area in the world since LandScan Global has the whole world demographic data and OpenStreetMap provides the worldwide road network for free. The potential applications of this framework are not limited to evacuation studies. With daily demand-modeling framework(Balmer et al., 2006), the normal daily traffic operation and prediction can be conducted to provide various application purposes for researchers and practitioners. Though implementation of intelligent transportation systems with modern communication technologies, such as connected vehicle technology (Lu, Han, & Cherry, 2013), to provide real-time travel information, a more accurate microscopic dynamic traffic simulation can be developed for various application purposes.

Acknowledgments

The authors would like to acknowledge Oak Ridge National Laboratory for providing the LandScan (2011)TM High Resolution USA Population Dataset, which is copyrighted by UT-Battelle, LLC, operator of Oak Ridge National Laboratory under Contract No. DE-AC05-00OR22725 with the United States Department of Energy. The United States Government has certain rights in this data set. Neither UT-Battelle, LLC nor The United States Department of Energy, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of the data set.

References

- Balmer, Michael, Axhausen, Kay, & Nagel, Kai. (2006). Agent-Based Demand-Modeling Framework for Large-Scale Microsimulations. *Transportation Research Record: Journal of the Transportation Research Board*, 1985(-1), 125-134. doi: 10.3141/1985-14
- Balmer, Michael, Cetin, Nurhan, Nagel, Kai, & Raney, Bryan. (2004). *Towards Truly Agent-Based Traffic and Mobility Simulations*. Paper presented at the Proceedings of the Third International Joint Conference on Autonomous Agents and Multiagent Systems - Volume 1, New York, New York.
- Bhaduri, B., Bright, E., Coleman, P., & Urban, M.L. (2007). LandScan USA: a high-resolution geospatial and temporal modeling approach for population distribution and dynamics. *GeoJournal*, 69(1), 103-117.
- Cetin, Nurhan, Burri, Adrian, & Nagel, Kai. (2003). *A large-scale agent-based traffic microsimulation based on queue model*. Paper presented at the IN PROCEEDINGS OF SWISS TRANSPORT RESEARCH CONFERENCE (STRC), MONTE VERITA, CH.
- Chen, X., & Zhan, F. B. (2006). Agent-based modelling and simulation of urban evacuation: relative effectiveness of simultaneous and staged evacuation strategies. *J Oper Res Soc*, 59(1), 25-33.
- Cova, T.J., & Johnson, J.P. (2002). Microsimulation of neighborhood evacuations in the urban-wildland interface. *Environment and Planning A*, 34(12), 2211-2230.
- data.seattle.gov. (2014). Seattle Real Time Fire 911 Calls. Retrieved 2014-3-1, from <https://data.seattle.gov/Public-Safety/Seattle-Real-Time-Fire-911-Calls/kzjm-xkqj>
- Dia, Hussein. (2002). An agent-based approach to modelling driver route choice behaviour under the influence of real-time information. *Transportation Research Part C: Emerging Technologies*, 10(5), 331-349. doi: [http://dx.doi.org/10.1016/S0968-090X\(02\)00025-6](http://dx.doi.org/10.1016/S0968-090X(02)00025-6)
- Ding, Li, Lebo, Timothy, Erickson, John S, DiFranzo, Dominic, Williams, Gregory Todd, Li, Xian, . . . Shangguan, Zhenning. (2011). TWC LOGD: A portal for linked open government data ecosystems. *Web Semantics: Science, Services and Agents on the World Wide Web*, 9(3), 325-333.

- Doniec, Arnaud, Mandiau, René, Piechowiak, Sylvain, & Espié, Stéphane. (2008). A behavioral multi-agent model for road traffic simulation. *Engineering Applications of Artificial Intelligence*, 21(8), 1443-1454. doi: <http://dx.doi.org/10.1016/j.engappai.2008.04.002>
- Haklay, Mordechai, & Weber, Patrick. (2008). Openstreetmap: User-generated street maps. *Pervasive Computing, IEEE*, 7(4), 12-18.
- Han, L.D., Yuan, F., Chin, S.M., & Hwang, H. (2006). Global optimization of emergency evacuation assignments. *Interfaces*, 36(6), 502-513.
- Han, L.D., Yuan, F., & Urbanik II, T. (2007). What is an effective evacuation operation? *Journal of urban planning and development*, 133(1), 3-8.
- Hendler, James, Holm, Jeanne, Musialek, Chris, & Thomas, George. (2012). US government linked open data: semantic. data. gov. *IEEE Intelligent Systems*, 27(3), 0025-0031.
- Janssen, Katleen. (2011). The influence of the PSI directive on open government data: An overview of recent developments. *Government Information Quarterly*, 28(4), 446-456.
- Jha, M., Moore, K., & Pashaie, B. (2004). Emergency evacuation planning with microscopic traffic simulation. *Transportation Research Record: Journal of the Transportation Research Board*, 1886(-1), 40-48.
- Lu, Wei. (2013). *Effects of Data Resolution and Human Behavior on Large Scale Evacuation Simulations*. (Ph.D), University of Tennessee, Retrieved from http://trace.tennessee.edu/utk_graddiss/2595 (2595)
- Lu, Wei, Han, Lee D, Liu, Cheng, Tuttle, Mark A, & Bhaduri, Budhendra L. (2014). *Evacuee compliance behavior analysis using high resolution demographic information*. Paper presented at the Transportation Research Board 93rd Annual Meeting.
- Lu, Wei, Han, LeeD, & Cherry, ChristopherR. (2013). Evaluation of Vehicular Communication Networks in a Car Sharing System. *International Journal of Intelligent Transportation Systems Research*, 1-7. doi: 10.1007/s13177-013-0060-

- Meister, Konrad, Balmer, Michael, Ciari, Francesco, Horni, Andreas, Rieser, Marcel, Waraich, Rashid A, & Axhausen, Kay W. (2010). Large-scale agent-based travel demand optimization applied to Switzerland, including mode choice.
- Murray-Tuite, Pamela, & Wolshon, Brian. (2013). Evacuation transportation modeling: An overview of research, development, and practice. *Transportation Research Part C: Emerging Technologies*, 27(0), 25-45. doi: <http://dx.doi.org/10.1016/j.trc.2012.11.005>
- Nagel, Kai, & Flötteröd, Gunnar. (2009). *Agent-based traffic assignment: going from trips to behavioral travelers*. Paper presented at the 12th International Conference on Travel Behaviour Research (IATBR), Jaipur.
- Naghawi, Hana, & Wolshon, Brian. (2011). *Performance of multi-modal evacuation traffic networks: A simulation based assessment*. Paper presented at the Proceedings of 90th Annual Meeting of the Transportation Research Board.
- Pel, AdamJ, Bliemer, MichielC J., & Hoogendoorn, SergeP. (2012). A review on travel behaviour modelling in dynamic traffic simulation models for evacuations. *Transportation*, 39(1), 97-123. doi: 10.1007/s11116-011-9320-6
- Robinson, David, Yu, Harlan, Zeller, William P, & Felten, Edward W. (2008). Government data and the invisible hand. *Yale JL & Tech.*, 11, 159.
- You, Jinsoo, Nedović - Budić, Zorica, & Kim, Tschangho John. (1998). A GIS - based traffic analysis zone design: technique. *Transportation Planning and Technology*, 21(1-2), 45-68. doi: 10.1080/03081069708717601
- Yuan, Fang, & Han, Lee. (2009). Improving Evacuation Planning with Sensible Measure of Effectiveness Choices. *Transportation Research Record: Journal of the Transportation Research Board*, 2137(-1), 54-62. doi: 10.3141/2137-07